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Mass wasting: October-November 1978 storm, Rennell Sound, Queen Charlotte Islands, British Columbia.

by
J.W. Schwab

Province of British Columbia
Ministry of Forests

Mass Wasting: October-November 1978 storm, Rennell Sound, Queen Charlotte Islands, British Columbia

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by
J.W. Schwab
Research Extension Forester

British Columbia
Ministry of Forests
Research Section,
Bag 5000,
Smithers, B.C.
V0J 2N0

Province of British Columbia
Ministry of Forests
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ABSTRACT

Mass wasting at the Rennell Sound area of the Queen Charlotte Islands was triggered during the storm of October 30 to November 1, 1978. The storm recorded two distinct 12-hour periods of intense rainfall (120 mm and 110 mm). Maximum average hourly windspeeds were reached during the periods of heaviest rainfall. A survey of storm impacts showed the occurrence of 264 mass movements: 113 in forested terrain, 126 in clearcuts and 25 from roads. The area disturbed by debris avalanches was 64 ha or 0.4% of the steep land area. Debris avalanches in clearcuts caused the largest impact, affecting 46.4 ha or 4.3% of clearcut terrain. In comparison, debris avalanches disturbed 15.4 ha (or 0.1%) of forested slopes, and 2.3 ha (or 1.9%) of roads. Debris torrents scoured 22.3 km of stream channel, mostly on forested slopes. Mass movements occurred at a frequency of $0.8/km^2$ in forested terrain, $11.6/km^2$ in clearcuts, $20.8/km^2$ from roads. The rate of mass wasting on man-modified terrain is 15 times greater than on forested terrain. The larger proportion of terrain occupied by clearcuts produced 5 times the acceleration found for roads. An equivalent storm could likely return within 5 to 10 years. Hillslopes are left susceptible to accelerated mass wasting for 15 to 20 years following logging. Forest management must recognize this "hazard" and give the utmost attention to developing environmentally acceptable harvesting systems for the sensitive west coast of the Queen Charlotte Islands.

1.0 INTRODUCTION

The October-November 1978 storm triggered extensive mass erosion in the steep mountainous terrain of the Queen Charlotte Islands. This mass erosion had major impacts: growing sites were destroyed, fish habitats degraded, and production costs and investment in forest roads lost. The erosion caused by the storm gave researchers an opportunity to compare mass wasting on man-modified terrain with that on forested terrain. The objectives of the study were

1) to identify all mass movements in the Rennell Sound study area that were triggered by the October-November, 1978 storm, including those that originated in roads, clearcuts, and natural forested terrain;
2) to quantify area disturbed and volume of material moved; and
3) to determine the relative rate and frequency of mass movements on roads, clearcuts, and forested terrain.

2.0 STUDY AREA

The Rennell Sound study area is located on the west coast of Graham Island, the major northern island of the Queen Charlotte Islands (Figure 1). The area lies along the eastern shores of Rennell Sound and covers 160 km^2 of forest land.

The bedrock geology of the Queen Charlotte Islands is described and mapped by Sutherland Brown (1968). Most of the Rennell Sound study area is covered by a thick accumulation of volcanic flows and pyroclastic rocks. Some sedimentary rocks, prophyritic andesite, and volcanic sandstone are also present. Much of the study area, except for a small area of plutonic rocks, is underlain with bedded limestone and argillite that outcrop along the steep coastal shores of Shields Bay. The topography of the study area has been extensively modified by glaciation, and morainal deposits are located throughout. The morainal material has a clay loam to sandy loam texture,

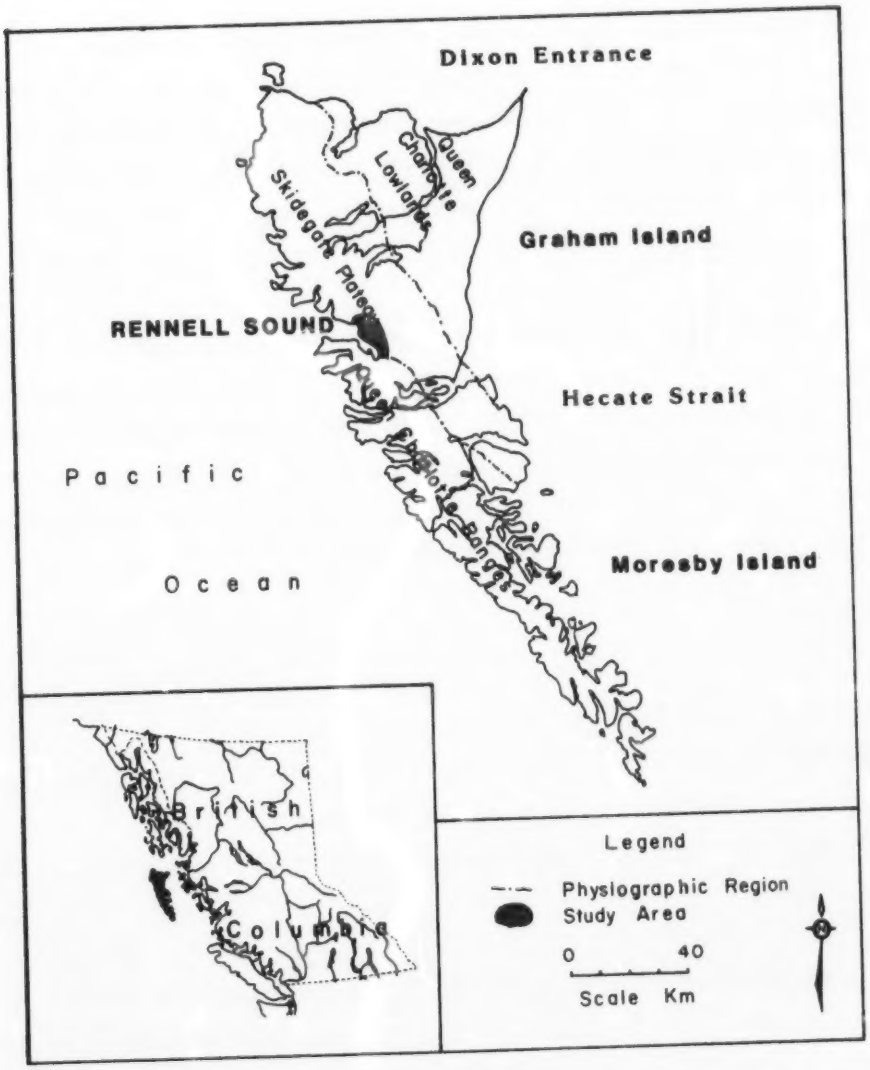

Figure 1. Rennell Sound study area located on the west coast of the Queen Charlotte Islands.

depending upon bedrock type and the degree of soil formation. Colluvium, the dominant surficial material, has a sandy loam to loamy sand texture. Alley and Thomson (1978) state that the abundance of colluvium and the intense weathering and mass movement processes that generate it serve as a constant reminder of the inherent instability of the terrain.

Stable terrain in the study area supports forest stands of western redcedar (Thuja plicata), yellow cedar (Chamaecyparis nootkatensis), shore pine (Pinus contorta) and western hemlock (Tsuga heterophylla). The soils are organic, developed on a saprolite veneer over bedrock, or Humic Podsols developed over till. The colluvial hillslopes support productive stands of Sitka spruce (Picea sitchensis) and western hemlock. Alder (Alnus rubra) is often a component of the more recently active slopes, while hemlock and cedar are more dominant on slopes that have not been recently active. The soils, depending upon their state of development, are regosolic, brunisolic, or podzolic, developed on the rubble of colluvial veneers, and on colluvial fans and aprons. Buried soil horizons can occur on the lower slopes. The rooting depth of all tree species is shallow, seldom extending below 30 cm into the mineral soil on well drained sites and below 15 cm on more poorly drained sites. The majority of roots are confined to surface organic soil horizons.

3.0 OCTOBER - NOVEMBER 1978 STORM

The climatic data and meteorological developments contributing to the rainstorms of October-November 1978, are presented in two reports by Schaefer (1979a; 1979b)[1]. The October-November 1978 rainstorm produced an accumulation of over 400 mm in five days in the area influenced by the most significant topographic barriers on the Queen Charlotte Islands (Appendix 1).

The Gospel Point climatological station,[2] located in the Rennell Sound study area and to the north of the storm centre, recorded its heaviest

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[1]Schaefer, D.G. 1979a. Meterological developments contributing to the Terrace area flood of early November, 1978. Available from: Atmospheric and Environment Service, Environ. Can., Vancouver.

Schaefer, D.G. 1979b. The multi-day rainstorm of October-November, 1978, on the Queen Charlotte Islands. Available from: Atmospheric and Environment Service, Environ. Can., Vancouver.

[2]Gospel Point climatological station, Air Studies Branch, B.C. Ministry of the Environment. The climatological day extends from 9:00 a.m. one day to 9:00 a.m. the following morning. The station, established May 4, 1976, is situated 12 m above sea level on a gentle west-facing slope.

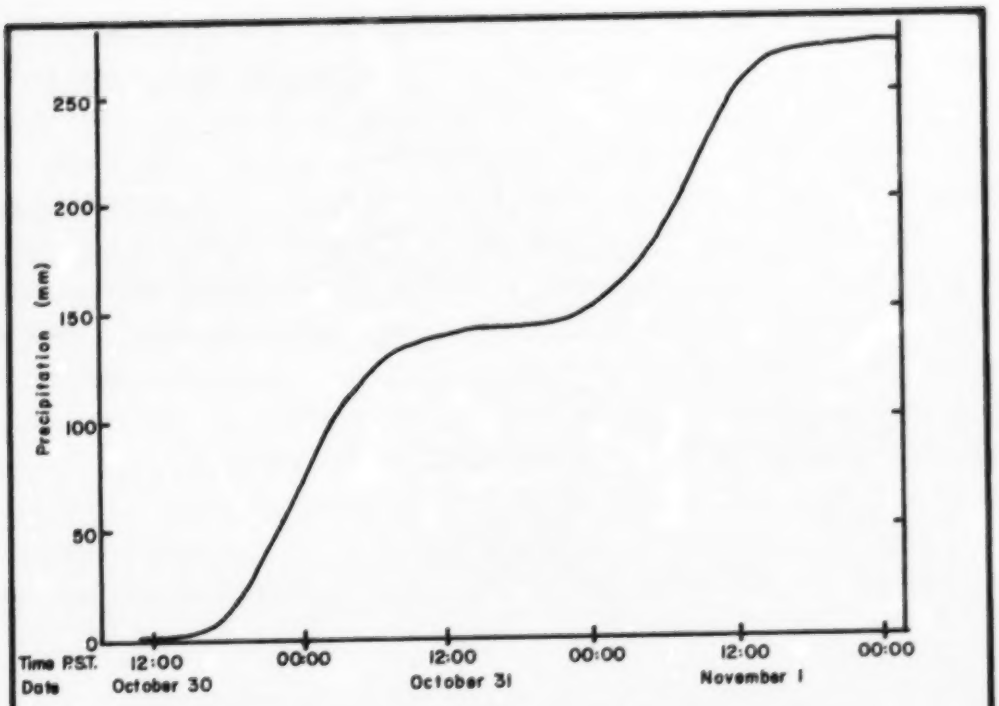

Figure 2 Mass curve of accumulated precipitation October-November 1978 storm, Gospel Point. Source: R. Marsh, pers. comm. 1978, B.C. Ministry of the Environment.

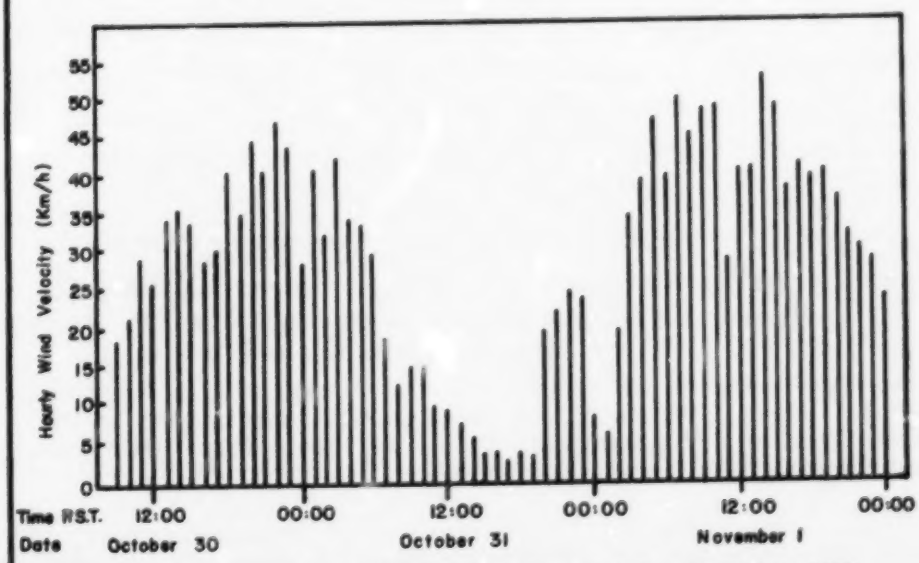

Figure 3 Average hourly wind velocity, October-November 1978 storm, Gospel Point. Source: R. Marsh, pers. comm. 1978, B.C. Ministry of the Environment.

rainfall on October 30 (135 mm). Lesser amounts fell October 31 (97 mm) and November 1 (52 mm). A mass curve of accumulated precipitation for the event shows two, distinct, twelve-hour periods of intense rainfall recording 120 mm and 110 mm respectively (Figure 2). Wind velocity follows the same pattern, with maximum speeds recorded during the periods of heavy rainfall (Figure 3). The maximum average hourly wind speed recorded for the storm was 53 km/h.

The short period of climatological records for the Rennell Sound study area precludes meaningful return period estimates. But records obtained at the Rennell Sound Camp[1] for a rainstorm in October 1974 indicate that the 1974 storm rivaled, and perhaps exceeded, the 1978 storm. Storm frequency analysis for Tasu Sound,[2] and its comparison with Rennell Sound storms, suggest that a storm similar in magnitude to the 1974 and 1978 storms will likely reoccur on the mid-west coast of the Queen Charlotte Islands, probably within a 10-year period and possibly returning within a 5-year time interval. (Refer to Appendix II for the probability of various storm occurrences).

Mass wasting caused by the 1978 storm commenced during the night of October 30, and continued on through October 31 and November 1 (G. Marshall, personal communication, 1978). Comparisons of dates of known mass movement occurrences with rainfall data at Rennell Sound and other climatological stations on the Queen Charlotte Islands, suggest that between 120 and 150 mm of rainfall within a 12 to 24 hour period is sufficient to trigger mass movements.

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[1]Rennell Sound "Camp Shields Bay", Atmospheric and Environment Service Canada, operated from September 1974 through November, 1975. The station was located 10 kilometres from the present Gospel Point station. The camp location generally experiences higher rainfall during storms than the Gospel Point station.

[2]Tasu Sound climatological station, Atmospheric and Environment Service Canada, is the longest recording station on the mid-west coast of the Queen Charlotte Islands, having commenced operation in September, 1963.

4.0 SURVEY METHODS

The survey recorded, within the limits imposed by access and terrain, all mass movements in the study area caused by the October-November 1978 storm. Small, back-slope failures along roads, and small failures in forests and clearcuts were excluded by setting a lower volume[1] limit of 25 m^3 which approximates a shallow failure covering an 80 m^2 area. Surface erosion (raindrop, rill, and gully erosion) was not recorded, although it transports significant amounts of material from bare mineral soil.

The survey was performed by travelling all access roads by vehicle or on foot, and by making foot traverses through some clearcuts. All mass movements at inaccessible sites in forests were visited by helicopter. Mass movements were categorized by their "place of origin": clearcut, road, or forest. Mass movements in clearcuts occur within the clearcut or result from the opening of the forest stand and the resultant windthrow along cutblock boundaries (Figure 4). Road-related mass movements originate in the road cutslope, in the road prism, or in sidecast or waste material; or else are obviously connected to road drainage (Figure 5). Mass movements in forests occur in natural forest stands and have no relationship to logging activities (Figure 6).

The following information was recorded at each failure site: location (watershed, cutting permit, road), mass movement process, date of harvesting or road construction, time since harvesting or construction, landscape position, landform, bedrock formation, slope gradient (origin), size, volume,

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[1]Volume is based on the estimate of the initial slide volume at the headscarp. No attempt was made to estimate the volume of entrailed organic debris.

and apparent triggering factor. Actual measurements were recorded on site when access and time permitted. Only estimates could be obtained at sites visited by helicopter and as a result, the survey grouped slope at the origin into three slope classes: (1) slopes greater than 36 degrees, (2) slopes between 20 and 36 degrees, and (3) slopes less than 20 degrees. Failure size and volume were also estimated. The impact on forest site and fish habitat was not assessed.

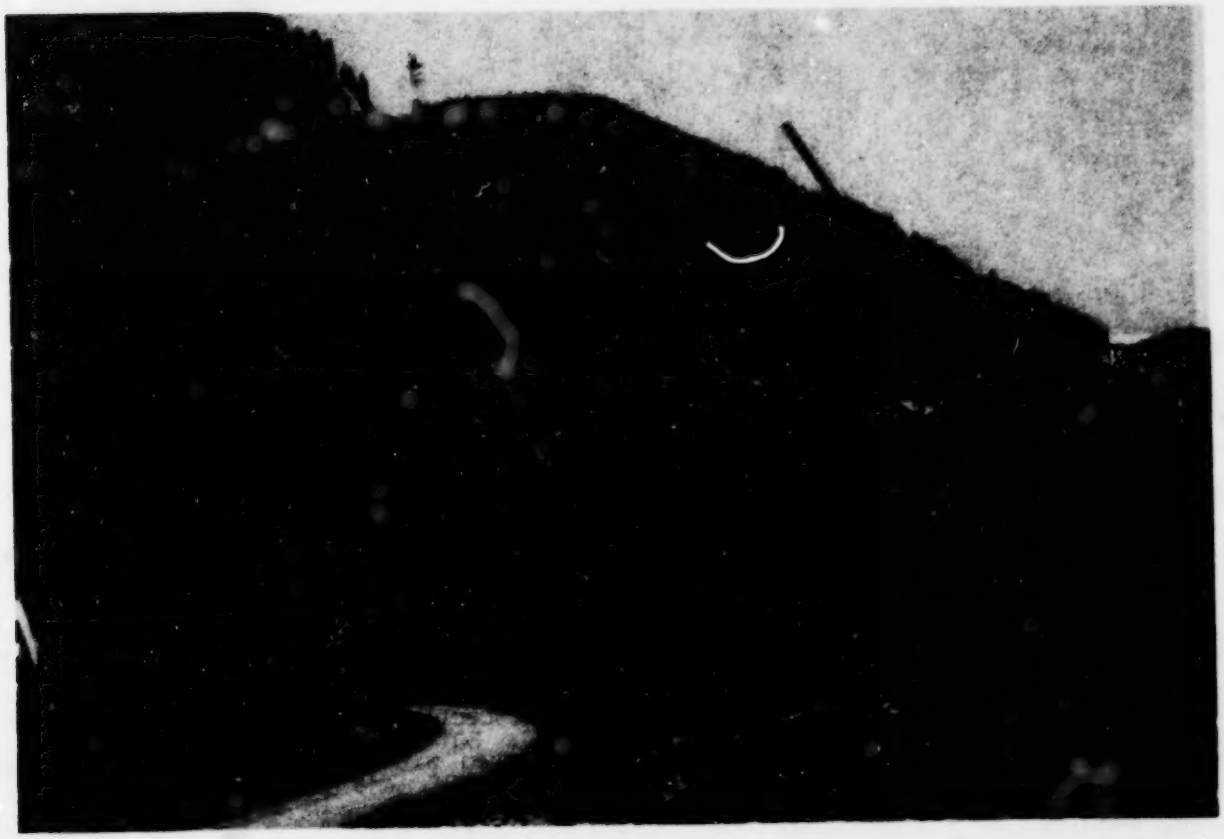

Figure 4. Debris avalanches in a clearcut eight years after logging. Note historic failures (arrows) in relation to the 1978 storm failures.

Figure 5. Debris avalanche from a road-fill failure.

5.0 SURVEY RESULTS AND DISCUSSION

The October-November 1978 storm caused 264 mass movements in the Rennell Sound study area: 113 in forests, 126 in clearcuts, and 25 from roads. The data are presented in Tables 1 and 2. The total land area affected by debris avalanches is 64 ha or 0.4% of the steep land in the Rennell Sound study area (hillslopes greater than 20 degrees). In perspective, this area covers 4.3% (or 46.4 ha) of clearcut steep slopes, compared with 0.1% (or 15.4 ha) of forested steep slopes and 1.9% (or 2.3 ha) of roads. In addition, debris torrents scoured approximately 22.3 km of stream channels (first, second and third order), mostly on forested slopes. The volume[1] of material moved by

[1] Initial slide volume is a conservative estimate of the total transported volume of mineral and organic debris.

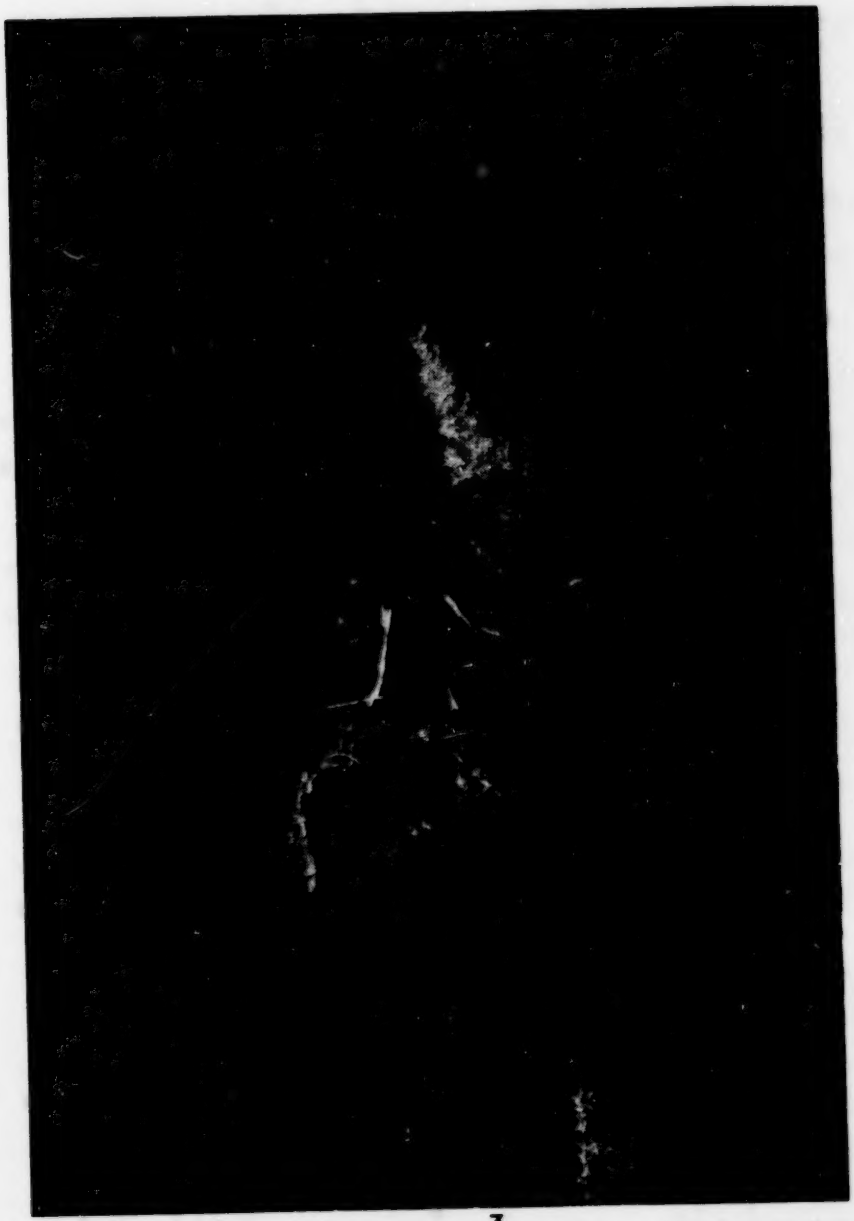

Figure 6. Debris slide on a forested slope.

debris avalanches is 80 700 m^3 with an average volume of 380 m^3. Forty percent are greater than 100 m^3 (Table 3). Debris avalanches originating in clearcuts and from roads are approximately two times larger than failures in forests. The largest debris avalanche originated in a clearcut and transported approximately 12 735 m^3. The volume of mineral and organic debris scoured and transported by debris torrents can only be estimated and

Table 1. Debris avalanches on forested and non-forested terrain, October-November 1978 Storm, Rennell Sound

Land Class	Steep Land area[a] (km^2)	Number of failures	Area Impacted (ha)	Material Transported[b] (m^3)	Average area (ha)	Average volume (m^3)	Per Unit Area: Frequency (No./km^2)	Per Unit Area: Area (ha/km^2)	Per Unit Area: Volume (m^3/km^2)	Management effects relative to forested terrain: Frequency basis	Management effects relative to forested terrain: Area basis	Management effects relative to forested terrain: Volume basis
Forest	138.6	82	15.4	17,330	0.2	210	0.6	0.1	125	X1	X1	X1
Clearcut	10.9	108	46.4	56,525	0.4	520	9.9	4.3	5,186	X17	X43	X41
Roads	1.2	20	2.3	6,920	0.1	350	16.7	1.9	5,766	X28	X17	X46
Total	150.7	210	64.1	80,775	0.3	380	1.4	0.4	540	X18[c]	36[c]	X42[c]

[a]Hillslope gradient steeper than 20 degrees.
[b]Initial slide volume (conservative estimate).
[c]Man-modified terrain (clearcuts plus roads).

Table 2. Debris Torrents on forested and non-forested terrain, October-November 1978 storm, Rennell Sound

Land Class	Steep Land area[a] (km^2)	Number of failures	Impact channel scour (m)	Average channel scour (m)	Debris torrent per unit area: Frequency (No./km^2)	Debris torrent per unit area: Channel scour (m/km^2)	Management effects relative to forested terrain: Frequency basis	Management effects relative to forested terrain: Area basis
Forest	138.6	31	13,130	420	0.2	95	X1	X1
Clearcut	10.9	18	6,820	380	1.7	625	X8	X7
Roads	1.2	5	2,360	470	4.2	1,966[b]	X19	X21
Total	150.7	54	22,310	410	0.4	148	X9[c]	X8[c]

[a]Hillslope gradient steeper than 20 degrees
[b]the large value per unit area of road is somewhat misleading, in that, actual impacts are downslope
[c]Man-modified terrain (clearcuts plus roads)

Table 3. Debris avalanches by volume class, October-November 1978 storm, Rennell Sound

Land Class	Number Failures	Volume m^3 25-49	50-99	99-499	500-999	1000-4999	5000+
Roads	20	7	5	7	---	---	1
Clearcuts	108	29	29	24	9	15	3
Forest	82	45	13	16	5	3	--
Total	210	80	47	47	14	18	4
	Percent	38%	22%	22%	7%	9%	2%

therefore is not presented. The average length of debris torrents is approximately 400 m. The longest was initiated by a debris avalanche in forested terrain, and travelled approximately one kilometre down a second order stream.

5.1 Frequency and Rate

Mass movements on forested terrain occur at a frequency of 0.8 per km^2. In comparison, the frequency for clearcut units is 11.6 per km^2, and from roads, 20.8 per km^2. The rate of mass movement for clearcuts and roads is, respectively, 14 times and 25 times the rate on natural forest terrain. The average rate of mass wasting in man-modified terrain (roads and clearcuts) is 15 times greater than in forested terrain - for which most is debris avalanche activity (18 times). Most striking is the size of debris avalanches on man-modified terrain. Relative to forested terrain the area and volume of clearcuts increased 43 times and 41 times, respectively; and of roads, 17 times and 46 times, respectively. Debris torrent activity relative to forested terrain increased by 8 times and 19 times, respectively, for clearcuts and roads. The length of channel scoured by torrents increased by 7 times in clearcuts and by 21 times for road.

Mass wasting rates reported for western North America show lower clearcut and higher road accelerated rates than experienced in the Rennell Sound Area (summary by volume) (Sidle et al. 1984). The higher rate found in Rennell Sound clearcuts may be due to the eposodic nature of the storm. Roads generally fail at a low threshold of triggering rainfall, and thus failures occur on a more regular or annual basis. Failures in clearcuts may occur more frequently with the big storms, and the effects may be more dramatic, as shown by the results of the 1978 storm. Different geology, weathering depths, drainage characteristics, precipitation characteristics, and resultant slope movement processes may also contribute to the rate differences. Therefore, areas with similar geology and climatic conditions to Rennell Sound could be expected to respond in a similar manner.

Roads contribute more mass wasting per unit area than do clearcuts. However, clearcuts occupy approximately 90% and road right-of-ways 10% of the steep land area modified by logging. If road and clearcut frequencies are weighted[1] accordingly, the larger proportion of terrain occupied by clearcuts produces 5 times more failures. Similar results can also be shown for volume transported and area disturbed by mass wasting activity. The relative rate difference for clearcuts at Rennell Sound correspond to the results of the mass movement inventory made by Gresswell et al. (1979) following a major storm in the Siuslaw National Forest.

5.2 Triggering Factors

Heavy rainfall and high winds are the dominant environmental factors contributing to debris avalanche and torrent activity on the Queen Charlotte Islands. The rainfall intensity and duration experienced during the 1978

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[1]Weighted calculation assumes 90% of man-modified terrain in clearcuts and 10% in roads: $11.6/km^2 \times 90\% = 10.4/km^2$ failure frequency clearcuts, and $20.8\ km^2 \times 10\% = 2.08/km^2$ failure frequency roads. Relative rate difference is 5 times.

storm seems to fit the limiting threshold curve described by Caine (1980). Rainfall influences slope stability when positive pore water pressure in shallow soils develops over an impervious layer (Swanston 1970; Sidle and Swanston 1982). Soil pipes 5 to 20 cm in diameter were observed at mid and lower slope debris avalanche headscarps, in surficial material, and in highly jointed "rotten" bedrock. The presence of pipes suggests that they are probably a contributing factor to slope failure. Experimentation by Pierson (1983) shows that the localized increases in pore pressure caused by a hydrostatic head in blocked or dead-end pipes may be sufficient to trigger failures at sites that would otherwise appear stable.

Wind forces transmitted to the soil are often considered as a probable triggering factor (Wilford and Schwab 1982). Evidence of windthrown trees at failure headscarps suggests the wind may have contributed to 33% of all failures (excluding roads); 40% of failures in forested terrain; and 26% of failures in clearcuts (along cutblock boundaries). The soils at these windthrow failure sites are generally shallow - 10 to 15 cm in depth over bedrock, organic, with slope gradients in excess of 40 degrees. It is still uncertain, however, whether these trees fall before, during, or after failure.

Debris torrents are often induced by storm runoff in steep, bedrock-controlled "V-notch" gullies. The torrent origins are grouped into categories (Table 4): debris avalanches from adjacent hillsides entering a channel accounted for 27%; debris slides at gully headwalls induced 49%; and 24% of the failures originated within the channel, possibly as a result of debris dam breakage. Windthrow may have been a contributing factor in 27% of the induced debris torrents. The most striking information obtained for debris torrents indicates that 60% of torrents originating at gully headwalls may have been triggered in part by wind.

The high incidence of earthquakes on the Queen Charlotte Islands is believed to be a major triggering factor for most rock slump-slides and for many of the debris avalanches and debris slides observed on Graham Island

Table 4. Origin of debris torrents on forested and clearcut terrain, October-November 1978 storm, Rennell Sound

Land Class	Number	Adjacent hillside	Gully headwall	Channel	Windthrow[a]
Forest	31	10 32%	12 39%	9 29%	6 19%
Clearcut	18	3 17%	12 66%	3 17%	7 39%
Total	49	13 27%	24 49%	12 24%	13 27%

[a]Observed windthrown trees at failure headscarp.

(Alley and Thomson 1978). However, there were no earthquakes that could have been felt on Graham Island during the period of October 28 to November 3, 1978. (G.C. Rogers, personal communication, 1979, Pacific Geoscience Centre, Sidney, B.C.)

5.3 Slope Gradient

Slope gradient is an important factor controlling slope stability. Forty-six percent of all slope failures occurred on slopes greater than 36 degrees, 13% on slopes between 20 and 36 degrees, and 2% on slopes less than 20 degrees. The additional 39% of the failures occurred in steep gullied terrain.

Debris avalanche activity is separated into two categories of slope: open slope failures not associated with gullies, and failures occurring in gullied terrain. In forested terrain, 37% of the observed debris avalanches occurred in gullied terrain, while in clearcut units there were only 23%. Most debris avalanches (56%) in forested terrain occurred on open slopes greater than 36

degrees; and a low percentage (7%) occurred on slopes between 20 and 36 degrees. No failures were observed on slopes of less than 20 degrees. In clearcut units the percentage occurrence of debris avalanches on open slopes greater than 36 degrees is slightly lower (52%) but more slides (22%) occur on slopes between 20 and 36 degrees; and three percent of the failures in clearcuts occur on open slopes of less than 20 degrees.

A comparison of debris avalanche activity on forested and clearcut terrain, with respect to slope gradient, indicates a 3.5-fold increase in failures in clearcut units on slopes of less than 36 degrees. This increase suggests that some factor(s) is involved on clearcut terrain that significantly alters slope stability (shear strength). This alteration likely results from lost root strength and/or changes in site hydrology - in particular, surface and subsurface water movement.

The slope data concur with the importance of slope gradient, as discussed in the literature (Bishop and Stevens 1964; Dryness 1967; O'Loughlin 1974; Megahan et al. 1978; Bourgeois 1979; and Gresswell et al. 1979). A more meaningful expression of the relative importance of slope gradient as a contributing factor would be in terms of slide frequency per unit area for a particular slope class. This information, however, is not available for the study area.

5.4 Bedrock

The 1978 storm triggered significantly different rates of mass wasting on the various bedrock formations in the Rennell Sound area (Table 5). The Kunga Formation shows the highest incidence of failure, with many slides located in steep "V-notch" gullies characteristic of the sedimentary unit. The plutonic rocks rank next in terms of failure frequency, however, all slides are relatively small. The heavily jointed and strongly fissured volcanic rocks of the Yakoun Formation exhibit a high rate of large mass movements. The volcanic rocks of the Masset Formation show a relatively low incidence of failure. The other bedrock formations found in the study area are minor in

Table 5. Mass wasting grouped by bedrock formation[a], October-November 1978 storm, Rennell Sound

Bedrock formation	Area Km^2	Number of failures	Frequency[b] Number/Km^2
Yakoun	25.10	92	3.66
Masset	113.65	96	0.84
Post-tectonic Plutons	2.81	14	4.98
Syntectonic Plutons	6.29[c]	---	----
Kunga	4.34	61	14.06
Longarm	1.61	--	----
Maude	0.26	--	----
Karmutsen	0.27	--	----
Deep Surficial Deposits	6.21	1	0.16
Total	160.54	264	1.64

[a]Bedrock formations from Sutherland Brown (1968).
[b]Frequency is for the total land area in the study area. Flat terrain has not been removed from the calculation.
[c]Flat lying and highly active on steep terrain outside the study area.

extent and exhibit no failures. The syntectonic plutons are noteworthy in that, outside the study area along the Queen Charlotte Range, these rocks exhibit high rates of failure in steep gullied clearcut terrain.

The geomorphic evidence of past mass wasting associated with the Yakoun and Kunga Formation suggests that factors related to these rock units contribute to slope instability. The units are characteristically steep and gullied. The heavy surface jointing and high weatherability of the Yakoun rocks probably play a significant role in reducing mechanical support of surface materials. The jointing and fissures in these volcanic rocks also provide avenues for deep penetration of ground water. The water probably surfaces close to the contact between the Yakoun and less weathered Kunga Formation. This would account, in part, for the high rate of failure originating close to the contact near gully head walls on the Kunga Formation. Non-weathered intrusive sills also control a large failure zone in the Kunga Formation. The sills protrude above the Kunga rocks, which exhibit a comparatively high degree of surface jointing and weathering. These sills are impervious and may form a perched water table during periods of excessive subsurface water flow.

5.5 Mass Movement Occurrence Since Logging

Mass movements evaluated by time since logging was started show that slope stability reduces dramatically approximately four to six years following timber felling (Table 6). The reduced slope strength is probably due to root decay and the resultant loss of a reinforcing root mat. Similar results have been demonstrated by Bishop and Stevens (1964), O'Loughlin (1974), Burroughs and Thomas (1977), and Ziemer and Swanston (1977). The continued high level of slope failures on clearcuts up to 11 years old[1] indicates that there is an inability for natural vegetation to re-establish a reinforcing root mat. Information reported by Nakano (1971) and Megahan et al. (1978) indicates that accelerated mass movement activity will continue for 15 to 20 years following

[1]The oldest logging on steep slopes in the study area at the time of the 1978 storm was 11 years.

Table 6. Debris avalanches and debris torrents evaluated by time since logging, October-November 1978 storm, Rennell Sound

Years since felling	Number	Number per km^2 steep terrain	Percent
0 - 3	27	6.6	13.6%
4 - 6	54	16.4	33.8%
7 - 9	19	12.2	25.2%
10 - 11	26	13.3	27.4%
Total	126	48.5	100%

timber felling. Once root strength re-establishes, failure rates return to pre-logging (natural) levels. Retrogressive failures in gullied terrain in the Rennell Sound area may extend the time frame beyond 20 years.

5.6 Roads

Most road failures (84%) triggered during the 1978 storm were confined to 3.6 km of the 48 km of road constructed on steep terrain. The sections of road where failure occured were six to nine years old, built with crawler tractors and known to have repeatedly failed since their original construction. Nine of the failures (36%) were attributed to a combination of factors: poor location through active gully headwalls; indiscriminate dumping of waste material into headwalls; and the lack of full benched roads with large organic debris incorporated into the fill. The most glaring problem responsible for 14 to 56% of road failures is inadequate road drainage. In general, these roads lacked sufficient cross drains and ditches, and inactive haul roads were not cross ditched or put-to-bed. A low frequency of failures on roads constructed since 1976 probably reflects a shift from crawler tractors to backhoes for subgrade construction. In addition, terrain hazard maps have improved planning, and road construction crews are more generally aware of road-related stability problems.

6.0 MANAGEMENT IMPLICATIONS

Man's activity has accelerated the rate of mass wasting by 15 times that found in the undisturbed forest. Roads induce the greatest number of failures per unit area. However, the rate is misleading in that the impact is confined to short sections and does not reflect road construction throughout the study area. Efforts to reduce road-related failures have substantially reduced failures on newly constructed roads. Much of the reduced frequency of failure can be attributed to a greater general awareness of stability problems, and to improved location and construction techniques. Road maintenance and adequate drainage requires constant attention. In particular, closed roads require adequate cross ditching and out-sloping to ensure drainage.

Clearcuts contribute the largest accelerated impact from man-modified terrain. Root strength deterioration in clearcuts has a dramatic effect on slope stability, evident in the greatly increased rate of mass wasting four years following logging. Root strength decay, relative to the regrowth of new roots on pre-logged forest stands, leaves hillslopes susceptible to accelerated mass wasting for probably 15 to 20 years following logging. Storms of sufficient magnitude to trigger mass wasting, similar to the October-November 1978 storm, will likely reoccur on the west coast of the Queen Charlotte Islands within 5 to 10 years. The time interval of minimum root strength and high probability of an extreme storm suggests that there is an "extreme hazard" for accelerated clearcut failures following logging. Forest management practices should therefore consider this "hazard" when planning operations in unstable terrain. Actively failing terrain units should not be logged but maintained as Protection Forests. Terrain units of moderate instability can be successfully harvested if silvicultural and harvesting techniques that maintain vegetation and enhance root regrowth are employed. The time frame for accelerated mass wasting could thus be narrowed, thereby reducing the probability of slope failure.

The forest industry must give the utmost attention to developing environmentally acceptable planning and harvesting systems for the easily destabilized west coast of the Queen Charlotte Islands. If not, future storms may destroy both valuable downslope resource investments in second-growth forests and productive fish streams.

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APPENDIX II

Table 1. Probable storm magnitudes for Tasu Sound[a]

Type of storm	Expected precipitation (mm) 1 day Period	3 day period
2 day period		
1 year	146	209
5 year	171 (4)[b]	241 (5)[b]
10 year	196	276
15 year	211	295
20 year	221	306
25 year	229	320
50 year	253	384
100 year	276	283
maximum recorded	190	283

244
290 (3)[b]
336
364
382
397
485
361
361

[a]Values calculated are based on the extremes recorded for the 17-year period (1963-1979).
[b]Bracketed value indicates the number of times the storm has been equalled or exceeded in 17 years.

Table 2. Probability of various storm occurrence[a]

Type of Storm (T)	Time Interval in Years(r) 1	2	5	10	15	20	25	50	100
	Risk Factor in Percent								
2 year	50	75	97	99	--	--	--	--	---
5 year	20	36	67	89	96	99	--	--	---
10 year	10	19	41	65	79	88	93	99	---
15 year	7	13	29	50	65	75	82	97	100
20 year	5	10	23	40	54	64	72	92	99
25 year	4	9	18	34	46	56	64	87	98
50 year	2	4	10	18	26	33	40	64	87
100 year	1	2	5	10	14	18	22	39	63

[a]The column under the 5-year time interval and opposite the 5-year storm shows that there is a 67% chance that the 5-year storm will occur in the 5-year period. Similarly, there is a 10% chance that a 50-year storm will occur. Probability calculated by

$$1-(1-\frac{1}{T})^{r}.$$